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Determination of Typical Operating Conditions for RCA Tubes Used as Linear RF Power Amplifiers

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During the past several years, there has been a tremendous increase in the use of single-sideband, suppressed-carrier transmission in amateur-radio radiotelephony. This type of transmission offers several advantages over the widely-used amplitude modulation methods. These advantages include reduced band-width and the elimination of heterodyne-interference problems. More useful power can be obtained with the same tubes and power supplies or, conversely, smaller tubes and power supplies can be used to deliver the same useful power.

With high-level amplitude modulation, a carrier and two groups of sideband frequencies are generated. The total power in the two sidebands at 100 per cent modulation is equal to one half of the carrier power. Thus, for every 100 watts of total transmitted power, 67 watts is in the carrier and 16.5 watts is in each sideband. Yet, one sideband contains all of the necessary intelligence for communication (provided certain receiver requirements are met).

Half the Bandwidth

Single-sideband, suppressed-carrier transmission utilizes only one sideband. By the elimination of the other sideband, the bandwidth is cut in half. By suppression of the carrier, heterodyne interference is eliminated. Only 16.5 watts of power is required to convey the same intelligence. Conversely, if the original 100 watts of power is transmitted in a single sideband, six times the former useful power will be obtained.

The literature contains considerable information on various methods of generating single-sideband, suppressed-carrier signals. However, little information is available on the choice of tubes for amplifying these signals and the methods of calculating typical operating conditions for these tubes.

Linear RF Amplifiers

Single-sideband signals must be amplified by linear rf amplifiers. These amplifiers are identical to af power amplifiers except that resonant tank circuits are used in the grid and plate circuits instead of audio-frequency transformers. Consequently, the tube manufacturer's ratings for af power amplifier and modulator service for class A, AB_1, AB_2, and class B and typical operating conditions will apply, provided the tube is also capable of operating at the higher frequencies involved. The same derating factors for plate voltage and input versus frequency shown by the manufacturer for class-C telegraphy ratings should be applied to single-sideband operation at the frequencies where they become applicable.

Because the tank circuits act as energy-storage systems, it is not necessary (as in case of audio work) to use two tubes in push-pull in class-AB or class-B, linear, rf amplifiers. However, if only one tube is used, the rf harmonics will be higher thereby making the TVI problems more severe.

Although the manufacturer's ratings are based on 100 per cent modulation with sine-wave signals, normal voice modulation reaches this condition only on the peaks of modulation. The ICAS ratings shown by RCA have

** Power Tube Engineering, Lancaster, Pa.*

taken this factor into account. Consequently, no attempt should be made to operate above these maximum ratings. Such operation will result in shorter tube life and the possibility of early tube damage during transmitter adjustment or unexpected overloads such as microphone "howl."

Since only rf power amplifiers are being considered, class A operation will not be discussed further. Of the remaining classes, AB_1 operation with tetrodes or pentodes is the simplest since only the plate- and screen-voltage supplies require good regulation.

Table I includes the maximum ratings and typical operating conditions for several RCA tubes used as linear rf power amplifiers. If it is desired to operate at conditions other than those given, typical conditions can be calculated by means of the following procedure:

1. Make sure E_b is within tube ratings.
2. Refer to the published curves. On the average plate characteristics curves, select a point on the zero grid-voltage curve near the "knee," and record i'_b,* and e_{bmin}; from the average screen-grid characteristics curves, determine i'_{c2} for this point.
   (E_{c2} equals the value shown for the curves used.)
3. Calculate I_{bms}: $I_{bms} = i'_b/3$.
4. Calculate PD:
   $$PD = \frac{I_{bms}}{4}(E_b + 3e_{bmin}).$$
5. Calculate SI: $SI = E_{c2}i'_{c2}/4$.
6. Calculate PI: $PI = E_b I_{bms}$.
7. Check the values found in steps 4, 5, and 6 to determine whether they are within tube ratings. Normally, they will be within ratings for AB_1 operation. If they are not, a lower value of i'_b (either in the negative-grid region or at a lower screen voltage) must be selected and steps 2 through 7 repeated.
8. Calculate PO: $PO = PI - PD$.
9. Calculate I_{bo}: $I_{bo} = I_{bms} / 5$.
10. E_{c1} can now be found on the plate characteristics curves as the grid voltage where the plate voltage is E_b and the plate current is I_{bo}.
11. $E'_g = [E_{c1}] + e_{cm}$.
    This value of E_g is the absolute value of E_{c1} (the brackets mean ignore the sign) plus the algebraic value of e_{cm} (include the sign). If the original point in step 2 was selected on the zero grid-voltage curve, then e_{cm} is equal to zero and
    $$E'_g = [E_{c1}].$$
12. Calculate I_{c2}: $I_{c2} = i'_{c2}/4$.
13. Calculate DP: $DP = \frac{E'_g i'_{c2}}{2}$ (for AB_1 operation, $i'_{c1} = O$ so DP is zero).

*

E_b	*Dc plate voltage.*
e_{bmin}	*Minimum plate voltage for the required peak current (from the characteristics curves).*
E_{c2}	*Dc screen voltage.*
E_{c1}	*Dc control grid voltage.*
e_{cm}	*Maximum grid-voltage drive to obtain the required peak plate current at a given minimum plate voltage.*
E'_g	*Peak value of grid-voltage swing.*
I_{bms}	*Maximum-signal, dc plate current.*
I_{bo}	*Zero-signal, dc plate current.*
i'_b	*Instantaneous peak plate current.*
I_{c2}	*Maximum-signal, dc screen current.*
i'_{c2}	*Instantaneous peak screen current.*
i'_{c1}	*Instantaneous peak grid current.*
PD	*Plate dissipation at maximum signal.*
PI	*Plate power input at maximum signal.*
PO	*Power output at maximum signal.*
DP	*Driving power at maximum signal.*
SI	*Screen input at maximum signal.*

Class-AB_2 Tetrode or Class-B Triode Operation

Class-AB_2 tetrode and class-B triode operation provide more power than class-AB_1 operation, but have the disadvantage of placing stiffer requirements on the driver and grid-bias supply regulation.

Calculation of typical operating conditions other than those given in the tube data sheets is slightly more complicated for class-AB_2 and class-B operation than for class AB_1, but is still relatively simple with the procedure outlined below:*

1. Make sure E_b is within tube ratings.
2. Assume a value of I_{bms}. A good starting point is at
   $$I_{bms} = \frac{3 \text{ (rated PD)}}{E_b}.$$
   Check this value to see whether it is within ratings. If it is not, use the maximum rated value of I_{bms}.
3. Calculate i'_b: $i'_b = 3I_{bms}$.
4. From the plate characteristics curves, select a value of e_{bmin} near the "knee" of the curves at which i'_b can be obtained. Also record E_{c2}, e_{cm}, i'_{c1} and i'_{c2} for this point.
5. Calculate PD:

* *Calculation for tetrodes is discussed; the triode case is the same except for the omission of the calculation of screen-input power.*

$$PD = \frac{I_{bms}}{4}(E_b + 3e_{bmin}).$$

6. Calculate SI: $SI = \frac{E_{c2} i_{c2}}{4}$

7. Calculate PI: $PI = E_b I_{bms}$.

Check the values found in steps 5, 6, and 7 to determine whether they are within the maximum ratings for the tube type. If the calculated values exceed the maximum ratings, choose a lower value of I_{bms} and repeat steps 3 through 7.

If the plate dissipation and input are below the maximum ratings but the screen input is high, it may be possible to choose a higher value of e_{bmin} in step 4 (and repeat steps 5, 6, and 7) to get all values within ratings. The reverse case can also be applied.

If all the values are well below maximum ratings, a higher value of I_{bms} can be chosen in step 2, and steps 3 through 7 repeated to see whether the operation is still within ratings. If so, this latter set of operating conditions will provide slightly more power output.

When values that are slightly below the maximum ratings are obtained for plate dissipation, screen input, and plate input,, the corresponding value of I_{bms} represents the maximum value which can be used at the original plate voltage selected. Lower values of I_{bms}, which give more conservative operation but less power output, can also be used.

Once the value of I_{bms} is selected, the remainder of the calculation follows steps 8 through 13 shown for class AB_1 operation. The driving power (DP) calculated does not include the rf tube and circuit losses. Consequently, for adequate performance, at least ten times this value of power should be available from the driver.

The following example illustrates the calculation of "typical operation" conditions for the class-AB_2, CCS operation of the type 807 with an E_b of 600 volts:

1. The maximum plate voltage rating is 600 v.
2. Determine I_{bms}:

$$I_{bms} = \frac{3\ (\text{rated PD})}{E_b} = \frac{3\ (25)}{600} = .125 \text{ amp.}$$

This value is above the maximum-signal, dc plate-current rating (from tube handbook or tube bulletin); therefore, the maximum rated value of 120 ma will be used as a first approximation.

3. $i'_b = 3I_{bms} = 3\,(120) = 360$ ma.
4. From the 300-v E_{c2} curves, *Fig. 1,* select $e_{bmin} = 90$ v, and read e_{cm} (= + 12 v). From *Figures 2* and *3,* read $i'_{c1} = 12$ ma, and $i'_{c2} = 35$ ma, respectively.

5. $$PD = \frac{I_{bms}}{4}[E_b + 3(e_{bmin})]$$

$$= \frac{120}{4}[600 + 3(90)] = 26 \text{ w.}$$

6. $$SI = \frac{E_{c2} i_{c2}}{4} = \frac{300(.035)}{4} = 2.6 \text{ w.}$$

7. $PI = E_b I_{bms} = 600\,(.120) = 72$ w.

PD and PI are both above ratings, and a lower value of e_{bmin} at the required current cannot be found on the curves. Therefore, a lower value of I_{bms} must be chosen; try a value of 100 ma, and repeat steps 3 through 7:

3. $i'_b = 3\ (100) = 300$ ma.
4. From the 300-v E_{c2} curves: $e_{bmin} = 70$ v, $e_{cm} = +\ 7$ v, $i'_{c1} = 8$ ma, $i'_{c2} = 35$ ma.

5. $$PD = \frac{.100}{4}[600 + 3(70)] = 20.3 \text{ w.}$$

6. $$SI = \frac{300(.035)}{4} = 2.6 \text{ w.}$$

7. PI = 600 (.100) = 60 w.

These values are within ratings; therefore, the remainder of the calculations can be completed:

8. PO = PI − PD = 60 − 20.3 = 39.7 w.

9. $$I_{bo} = \frac{I_{bms}}{5} = \frac{100}{5} = 20 \text{ ma.}$$

10. E_{c1} (from *Fig. 1*) = −35 v.

11. $$E'_g = [E_{c1}] + e_{cm} = 35 + (+7) = 42 \text{ v.}$$

12. $$I_{c2} = \frac{i'_{c2}}{4} = \frac{35}{4} = 8.7 \text{ ma.}$$

13. $$DP = \frac{E'_g i'_{c2}}{2} = \frac{42(.008)}{2} = .17 \text{ w.}$$

These values compare reasonably well with the published values.

(*Continued on Page 5*)

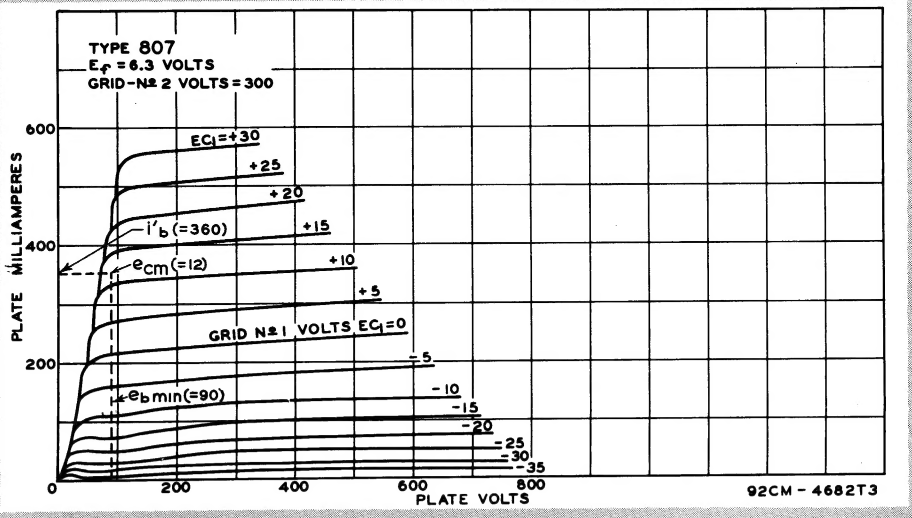

Fig. 1. Average plate characteristics for the type 807 tube (grid-No. 2 voltage = 300).

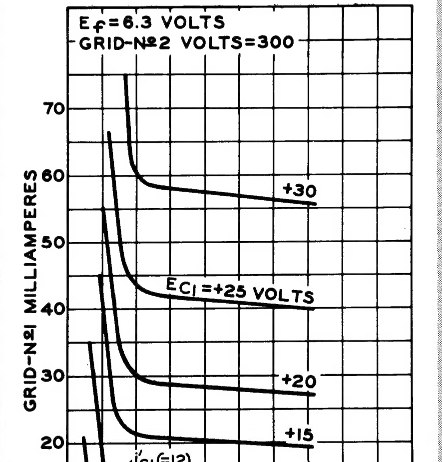

Fig. 2. Average control-grid characteristics for the type 807 tube grid-No. 2 voltage = 300).

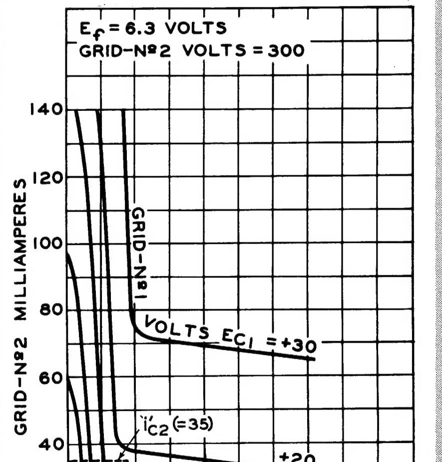

Fig. 3. Average screen-grid characteristics for the type 807 tube grid-No. 2 voltage = 300).

(*Continued from Page 3*)

Table I shows the maximum ratings and typical operating conditions for several popular RCA tubes in linear rf amplifier service for single-sideband, suppressed-carrier transmission.

It should be remembered that the typical operating conditions shown by the manufacturer (or calculated by the preceding methods) are approximate only. Minor adjustments are usually made in actual operation by varying the grid bias or screen voltage slightly. In linear rf amplifier circuits for single-sideband, suppressed-carrier transmission, it is particularly important to check the actual operating conditions when the transmitter is first set up to assure that linear operation within the maximum tube ratings is being obtained.

Table I—Ratings and Operating Conditions for RCA Tubes Used as Linear RF Power Amplifiers

			Maximum Ratings - Absolute Values							Typical Operation								
Tube Type	Class of Operation	Service	Plate Voltage (E_b)	Screen Voltage (E_{c2})	Max-Signal Plate Current (I_{bms})-ma	Max-Signal Plate Input (PI)-watts	Max-Signal Screen Input (SI)-watts	Plate Dissipation (PD)-watts	Grid Resistance -ohms	Plate Voltage (E_b)	Screen Voltage (E_{c2})	Grid Voltage (E_{c1})	Peak Grid Voltage (E'_g)	Zero-Signal Plate Current (I_{bo})-ma	Max-Signal Plate Current (I_{bms})-ma	Max-Signal Screen Current (I_{c2})-ma	Drive Power (DP) -watts	Max-Signal Power Output (PO)-watts
2E26	AB$_1$	CCS	400	200	75	30	2.5	10	30 K	400	200	-25	25	9	45	10		12
		ICAS	500	200	75	37.5	2.5	12.5	30 K	500	200	-25	25	9	45	10		15
	AB$_2$	CCS	400	200	75	30	2.5	10		400	125	-15	30	10	75	16	0.2	20
		ICAS	500	200	75	37.5	2.5	12.5		500	125	-15	30	11	75	16	0.2	25
4-65A	AB$_1$									1000	500	-85	85	15	85	12		40
		CCS	3000	600	150		10	65	250 K	1500	500	-85	85	15	90	7		70
										1750	500	-90	90	10	85	9		85
	AB$_2$									1000	250	-30	105	30	150	22	2.5	85
		CCS	3000	600	150		10	65		1500	250	-35	100	30	125	15	1.5	125
										1800	250	-35	90	25	110	13	1.0	135
4-125A	AB$_1$									1500	600	-90	90	30	110	9		80
		CCS	3000	600	225		20	125	250 K	2000	600	-94	94	25	120	3		115
										2500	600	-96	96	25	115	4		165
	AB$_2$									1500	350	-41	141	44	200	17	5.0	175
		CCS	3000	400	225		20	125		2000	350	-45	105	36	150	3	3.0	175
										2500	350	-43	139	47	130	3	2.5	200
4-250A	AB$_1$									2000	500	-88	88	55	200	11		230
		CCS	4000	600	350		35	250		2500	500	-90	90	60	215	7		310
										3000	500	-93	93	60	205	5		370
	AB$_2$									2000	300	-48	100	60	255	13	5.5	325
		CCS	4000	600	350		35	250		2500	300	-51	100	60	250	12	5.0	420
										3000	300	-53	100	62	236	16	4.5	520
807 1625	AB$_1$									500	300	-32	32	22	70	8		23
		CCS	600	300	120	60	3.5	25	100 K	600	300	-34	34	18	70	8		28
		ICAS	750	300	120	90	3.5	30	100 K	750	300	-35	35	15	70	8		35
	AB$_2$									500	300	-30	43	30	120	10	0.2	38
		CCS	600	300	120	60	3.5	25		600	300	-32	40	24	100	9	0.1	40
		ICAS	750	300	120	90	3.5	30		750	300	-35	48	15	120	10	0.2	60
811A	B									750		0	100	16	175		10	90
		CCS	1250		175	165		45		1250		0	78	25	130		4	120
										1000		0	93	22	175		7.5	125
		ICAS	1500		175	235		65		1250		0	88	27	175		6	155
813	AB$_1$									2000	750	-90	80	25	130	20		165
		CCS	2250	1100	180	360	22	100		2250	750	-95	85	25	125	26		190
		ICAS	2500	1100	225	450	22	125		2500	750	-95	90	25	145	27		245
829B Natural Cooling	AB$_1$									500	200	-20	40	20	100	20		35
		CCS	750	225	250	100	7	30	100 K	600	200	-18	36	40	100	18		44
		ICAS	750	225	250	120	7	40	100 K	750	200	-21	42	20	100	20		55
	AB$_2$									500	200	-18	50	30	180	26	0.6	60
		CCS	750	225	250	100	7	30		600	200	-20	50	26	155	22	0.4	65
		ICAS	750	225	250	120	7	40		750	200	-19	50	32	160	25	0.5	85
832A	AB$_1$									500	180	-30	60	14	70	7		22
		CCS	750	250	90	36	5	15	100 K	600	150	-30	60	12	60	7		23
		ICAS	750	250	115	50	5	20	100 K	750	150	-32	64	12	60	7		30
833A	B	ICAS	3300		500	1300		350		3300		-80	190	60	300		20	710
6146 6159	AB$_1$									400	190	-40	40	32	114	13		27
		CCS	600	250	125	60	3	20	100 K	500	185	-40	40	29	108	13		35
										600	180	-45	45	13	100	12		40
										600	200	-50	50	14	115	14		47
		ICAS	750	250	135	85	3	25	100 K	750	195	-50	50	12	110	13		60
	AB$_2$									400	175	-41	48	17	116	9	0.2	31
		CCS	600	250	125	60	3	20		500	175	-44	51	14	121	9	0.3	41
										600	165	-44	49	11	104	9	0.2	45
										600	190	-48	55	14	135	10	0.3	55
		ICAS	750	250	135	85	3	25		750	165	-46	54	11	120	10	0.4	65
6524	AB$_2$	CCS	500	300	150	70	3	20	30 K	400	200	-23	72	25	145	10	0.1	39
										500	200	-26	70	20	116	10	0.1	40
		ICAS	600	300	150	85	3	20	30 K	500	200	-25	76	25	145	10	0.1	50
										600	200	-26	76	21	135	13	0.1	57

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Typical Power Input and Plate-Voltage Values for popular Class C Telegraphy

RCA No.	Type	DC Power Input (watts)	DC Plate Volts
810	High-perveance triode	500	2000
811A	High-perveance triode (High Mu)	520*	1500
812A	High-perveance triode (Low Mu)	520*	1500
813	Beam Power	500	2250
833A	High-perveance triode	1000	2250
8000	High-perveance triode	500	2000
8005	High-perveance triode	600*	1500

*For two tubes

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